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**CORRELATION BETWEEN AIRCRAFT MSS AND LIDAR REMOTELY SENSED DATA ON
A FORESTED WETLAND IN SOUTH CAROLINA**

by

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ABSTRACT: Wetlands in a portion of the Savannah River swamp forest, the Steel Creek Delta, were mapped using April 26, 1985 high-resolution aircraft multispectral scanner (MSS) data. Due to the complex spectral characteristics of the wetland vegetation, it was necessary to implement several techniques in the classification of the MSS imagery of the Steel Creek Delta. In particular, when performing unsupervised classification, an iterative "cluster busting" technique was used which simplified the cluster labeling process. In addition to the MSS data, light detecting and ranging (LIDAR) data were acquired by National Aeronautics and Space Administration (NASA) personnel along two flightlines over the Steel Creek Delta. These data were registered with the wetland

classification map and correlated. Statistical analyses demonstrated that the laser derived canopy height information was significantly correlated with the Steel Creek Delta wetland classes encountered along the profiling transect of the LIDAR data.

INTRODUCTION

It is difficult to collect biophysical information such as vegetation type, spatial distribution, height, biomass, and canopy density in wetland environments (Carter, 1977, 1982). For this reason there has been interest in recent years in the use of remotely sensed data for collecting information on some of these important biophysical variables (Butera, 1983; Jensen, 1986; Jensen et al., 1986). This research summarizes the use of two improved, high-resolution remote sensor systems flown on aircraft to evaluate several of these important variables for the Steel Creek Delta wetland environment on the Savannah River Plant (SRP) located near Aiken, South Carolina (Figure 1). Wetland in situ data on community composition were available from the Savannah River Ecology Laboratory, University of Georgia. A Daedalus AADS-1268 multispectral scanner (MSS) operated for the Department of Energy by EG&G of Las Vegas, Nevada, obtained data on the type and spatial distribution of wetland vegetation. A light detecting and ranging (LIDAR) remote sensing system operated by NASA Wallops Space Flight Center was used to obtain height information for two transects in the study area. The MSS and LIDAR data sets were registered and their information content correlated.

THE STEEL CREEK DELTA STUDY AREA

The L Reactor on the SRP discharged cooling water into Steel Creek from 1954 to 1968. This thermal effluent to Steel Creek eventually entered the Savannah River swamp creating a delta (Figure 1). The cooling water effluent affected the Savannah River swamp forest in this region composed primarily of Bald Cypress (Taxodium distichum) and Water Tupelo (Nyssa aquatica). The reactor was not operated from 1968 to the fall of 1985. It was reactivated in 1985 introducing thermal effluent once again into Steel Creek via a large cooling lake, L Lake. The water leaving L Lake flows down the lower portion of Steel Creek to the delta. Both flow and increased water levels are being monitored to determine if they are having an effect on the wetland environment of the Steel Creek Delta.

This wetland environment is composed of the following types of land cover:

- OW - Open Water
- EM - Emergent Marsh (Persistent and Nonpersistent)
- SS - Scrub/Shrub
- DSF - Deciduous Swamp Forest
- DBF - Deciduous Bottomland Forest

These wetland classes are compatible with the U.S. Fish and Wildlife wetland classification system (Cowardin et al., 1979). The species within each wetland class are summarized in Table 1.

THE REMOTE SENSOR SYSTEMS

Daedalus AADS-1268 Multispectral Scanning (MSS) System

This sensor system (Figure 2) collected data on April 26, 1985 using the spectral bands summarized in Table 2. The sensor was flown at 4000 ft (1219 m) above ground-level (AGL) with a 2.5 milliradian field-of-view resulting in pixels with a spatial resolution of 2.8 x 2.8 meters. The data were recorded in 8-bits (brightness values from 0 to 255). The data were obtained at approximately 10:30 a.m. in stable, cloud-free atmospheric conditions. A color infrared image of the study area is shown in Figure 3.

A low pass 2 x 2 pixel spatial moving average (Jensen, 1986) was applied to the April 26, 1985 data. The mean for each 2 x 2 pixel window was computed and placed in a new image file. This operation was performed for each band in the data set. This resulted in an April 26, 1985 data set that had pixel dimensions of approximately 5.6 x 5.6 meters. A 6 x 6 meter spatial resolution cell is shown adjacent to a 30 x 30 meter Landsat Thematic Mapper pixel and 80 x 80 meter Landsat Multispectral Scanner (MSS) pixel in Figure 4 to demonstrate the high spatial resolution of these aircraft MSS remote sensor data.

NASA Light Detecting and Ranging (LIDAR) Sensor System

The NASA LIDAR remote sensing system was used in a series of experiments on the SRP during June 1985. This LIDAR has two basic modes of operation (Krabill et al., 1986). In the bathymetry

mode, either the backscattered laser pulse or a specific laser stimulated response are temporally resolved. The second basic mode of operation is the fluoro-sensing mode where the laser induces responses from the terrain including Raman backscatter. Both the bathymetry and fluoro-sensing modes provide information on the height of the sensor above either the canopy or the ground, depending upon which is visible. For example, a typical LIDAR transect of a forested area might generate the height profile shown in Figure 5. This is computed from the altimetry data in which the slant range (laser pulse transit time) between the aircraft sensor system and the surface target is measured. Detailed discussions of both the bathymetry and fluoro-sensing modes of operation are described in Krabill et al. (1986). A diagram of the three-tier sensor system which contains a transmitter, receiver, and an optical sub-system is shown in Figure 6. The specifications of the laser used in these investigations are summarized in Table 3. The high pulse repetition rate, narrow pulse width, and moderate pulse power make this laser especially attractive for forestry surveying applications.

The LIDAR measures tree height using laser light as a differential altimeter (Krabill and Maclean, 1984; Aldred and Bonner, 1985; Maclean and Krabill, 1986). A short pulse of laser light approximately 7 nanoseconds (ns) in duration is emitted, and reflected out of the aircraft through a series of mirrors. When the laser pulse is intercepted by the forest canopy, a portion of

the pulse is reflected back to the aircraft. Of the remaining energy, some proceeds through the canopy and is reflected off the forest floor and back to the aircraft as a secondary return pulse. The time difference between the initial return from the tree canopy and the secondary return can be converted to a height measurement using the known value of the speed of light. System precision allows approximately plus or minus 0.30 m distance estimates with any single pulse.

The LIDAR system acquired and recorded data at the rate of 200 laser pulses per second. The aircraft typically flew over a target area at velocities of between 80 and 100 m/sec, providing an along-track data density potential of at least five measurements per meter. A beam divergence of 5 milliradian (mrad) and flying height of 150 m above the canopy resulted in a nominal pulse footprint of 0.7 m in diameter for one of the flightlines. Integration of all tree height measurements, over discrete units along the ground track of the aircraft, yielded specific profile areas which can be correlated to ground measurements of tree heights if available.

Two flightlines of LIDAR data were obtained over the Steel Creek Delta on June 13, 1985. This study evaluated flight lines 5/2 and 6/2 (Table 3; Figure 7). Flightline 5/2 was collected with the LIDAR system operating in a bathymetry or temporal measurement mode (Figure 8). Flightline 6/2 was flown in the fluorsensing data acquisition mode. However, when the LIDAR is operated in the fluorsensing mode, only 10% of the energy reflected from the terrain

is used to compute profile height information, making it more difficult to extract vegetation height information from these data.

The laser data were obtained at a pulse repetition rate of 200 pps on both flightlines. At the nominal 100 m/sec velocity of the aircraft, this resulted in an independent observation every 0.5 meters along the ground track for flightline 5/2. A 5 milliradian laser beam divergence was used on both passes. This divergence setting provided a footprint of approximately 1.6 meters for flightline 5/2 and 3.2 meters for flightline 6/2. Flightlines 5/2 and 6/2 were flown at 150 and at 300 meters respectively.

A 35 mm flight research camera controlled by an intervalometer collected vertical aerial photographs along each of the flightlines. This provided a photographic record of the exact flightline sensed by the profiling LIDAR system (Figure 8). Note how the small clump of trees at A is faithfully measured as well as the hardwood islands at B in Figure 9. The scale of each frame of the color vertical aerial photographs was a function of the focal length of the camera (35 mm) and the height of the camera above ground level at each exposure station.

DATA REGISTRATION

In order to compare biophysical measurements obtained by the MSS with those obtained by the LIDAR sensor system at the same point on the surface of the earth, it was necessary to register the two remotely sensed data sets together. Satellite platforms remain relatively stable approximately 900 km above the earth. Movements

that occur are usually minor and are systematically spread over large geographic areas. Since the distortion is usually linear, a simple least squares regression approach may be used to model the distortion and accurately register the different images to within ± 1 pixel. Unfortunately, with aircraft MSS or LIDAR data, image distortion can be a much greater problem. Lateral winds and vertical turbulence can cause random and sometimes severe aircraft movements (roll, pitch, and yaw) or variations in altitude and/or velocity while the sensor is scanning (Bernstein, 1983). Because of these problems, few have attempted geometric correction of aircraft MSS data (Ungar, 1982). When geometric correction is attempted, most deal with geometric rectification of a single flightline of MSS data to a map (Otepka, 1978; Kraus, 1978) or mosaicking the edges of several flightlines together (McGlone et al., 1979; McGlone and Mikhail, 1985; Gibson, 1985). Leckie (1980) found that aircraft thermal MSS data could be registered image-to-image if a sufficient number of ground control points were available.

The April 26, 1985 MSS data were geometrically corrected in a previous study (Christensen et al., 1986). Therefore, it was only necessary to scale and register the LIDAR profile data to the MSS data. This was accomplished using the following methodology. First, the 35 mm vertical aerial photographs acquired at the same time as the LIDAR data were mosaicked together using the appropriate fiducial marks for a complete flightline (a portion is shown in Figure 9). Then, the ground location of the LIDAR profile was

identified on the high resolution MSS data by visually displaying the MSS data on the CRT screen in a color-infrared, color-composite format. Individual trees found in both the MSS data and 35 mm remotely sensed data were easily identified. A number of individual trees found along the transect were then used as control points to identify the exact flightline path in the MSS data. While no registration accuracy assessment was made between the LIDAR and MSS derived profile locations, it is believed they were accurate to within ± 1 pixel.

The nominal scale wetland class information was then extracted from the MSS data for each pixel along the LIDAR profile line. One hundred and eighty-seven MSS pixels covered 1309 meters of the LIDAR transect. Not all of the LIDAR transect could be used since the MSS data covered only a portion of the Savannah River swamp around the Steel Creek Delta.

The LIDAR profile information was then correlated visually with the nominal scale wetland class information (Figure 10). The same control points used in determining the location of the LIDAR profile on the MSS imagery were identified on the plot. The common section of the LIDAR profile was identified and extracted resulting in a set of 2618 observations. The approximate distance covered on each MSS classified pixel by the LIDAR profile was seven meters. (The distance of the profile across each pixel was not the horizontal length of a pixel because the transect extracted from the MSS data was often on a diagonal). As the LIDAR observations

were collected every 0.5 meter, fourteen LIDAR observations represented each classified MSS pixel. A mean vegetation height was computed for each pixel by averaging the fourteen observations of LIDAR vegetation height for each pixel.

AIRCRAFT MSS DATA WETLAND CLASSIFICATION RESULTS

Results of image classification in other areas having complex wetland terrain suggested that an unsupervised classification is usually superior (Townshend and Justic, 1980; Shreirer et al., 1982). When performing an unsupervised classification, each pixel is assigned by the computer to a "cluster" based on its statistical characteristics in n dimensional feature space. Theoretically, pixels representing a given landcover type (e.g., Emergent Marsh) will cluster together in a unique region of spectral space. The pixels assigned to the various wetland vegetation clusters are then labeled by the analyst according to the position of a cluster in feature space and their relationship to the analyst's real world knowledge of the landscape.

Even though up to eleven spectral bands were available for analysis, only four were used in the unsupervised classification. Based on transformed divergence statistics computed by Jensen et al. (1984, 1986), band 3 (0.52 - 0.60 μm), band 5 (0.63 - 0.69), band 8 (0.91 - 1.05) and the middle-infrared band 9 (1.55 - 1.75) are optimum. Other wetland mapping studies have found that one green, one red, and at least one infrared band are usually optimal (Best et al., 1981).

Initially, 77 clusters were extracted from the 1985 MSS data. Plots of the clusters in red and near-infrared, 2 dimensional feature space for the April 26, 1985 data set are displayed in Figure 11. In addition to Persistent Emergent Marsh (PE), Nonpersistent Emergent Marsh (NPE), and Water (OW), two additional classes were discriminated using the April 26, 1985 imagery. The cluster plots show that the willow and buttonbush components of the scrub/shrub (SS) class could be differentiated and the tupelo and cypress components of the Deciduous Swamp Forest (DSF) class could be discriminated.

However, there was confusion between some of the Deciduous Swamp Forest (DSF) - Cypress clusters and Nonpersistent Emergent Marsh (NPE) and Deciduous Bottomland Hardwood (DBF). Therefore, in order to accurately discriminate between these important clusters which accounted for a large proportion of the data scene, an iterative "cluster busting" technique was developed to understand and properly label these mixed clusters. This procedure is described in a separate report (Jensen et al., 1987).

The classification map of the April 26, 1985 MSS data set is shown in Figure 12. The black areas in the swamp are Deciduous Bottomland Forest (DBF). The upland areas of the classification map were "masked out" by overlaying a digitized boundary onto both classification maps. The wetland acreage statistics for the 1985 classification maps are shown in Table 4.

The overall absolute accuracy of the April 16, 1985 wetland classification using multispectral aircraft MSS data was 88.46 percent. This was derived by comparing the detailed remote sensing wetland classification with in situ wetland mapping conducted by the Savannah River Ecology Laboratory in the Fall of 1995. Twenty-six ground control points were identified in the imagery and the classification for each pixel compared with the in situ data. The classification accuracy results are summarized in Table 5.

CORRELATION OF MSS AND LIDAR RESULTS

The registered LIDAR and MSS data yielded 187 paired observations of height and wetland class. Analysis of these data were performed to determine if there was a significant difference between mean height for each wetland class and whether this information could be obtained from the digital remote sensor data. The mean height for the seven wetland classes as derived from the MSS and LIDAR data are presented graphically in Figure 13. An analysis of variance (ANOVA) was computed using the mean height of each wetland class as the independent variable and the wetland class as the dependent variable. The results of the ANOVA are found in Table 6. An F-value of 58.46 indicated that there was a significant difference (0.0001) between the mean height of each wetland class and that it could be derived from remotely sensed data.

It was initially anticipated that either the precision of the LIDAR data, the registration accuracy between the LIDAR profiles and MSS transect, or the accuracy of the classified wetland types

might result in error of the estimated mean vegetation heights. Therefore, t-tests between each pair of wetland classes were computed. The mean heights of water, nonpersistent, persistent emergent marsh, and scrub-shrub were not significantly different at the 0.05 confidence level. Also, swamp forest and bottomland hardwoods were not significantly different. This was anticipated since swamp forest and bottomland hardwoods generally have similar canopy heights; however, scrub-shrub should have been significantly different than either water or the emergent marsh categories. Also, it was not surprising that water and the emergent marsh categories were similar in height.

Based on this initial analysis, the two marsh categories (persistent and nonpersistent) and water were pooled together and evaluated using an additional analysis of variance. This model was again significant at the 0.0001 level with an F-value of 88.42 (Table 7). A t-test on these collapsed data revealed that all the categories were significantly different with the exception of the swamp forest and bottomland hardwoods. Mean heights for these five wetland classes are portrayed graphically in Figure 14.

Based on the significant relationship between wetland class and LIDAR derived height information per pixel along the flight-line, it was possible to extend the logic through space over the entire delta region. A three-dimensional portrayal of the height of the wetland communities of the Steel Creek Delta is shown graphically in Figure 15. Such information should be correlated in the

future with biomass and/or stand density information from known study areas in the swamp to determine the ability of the MSS and LIDAR data sets synergistically to provide regional biomass estimates.

CONCLUSIONS

Aircraft MSS data of wetland environments obtained in 1985 were used to derive accurate wetland class information on a pixel basis. NASA aircraft LIDAR data were used to accurately measure the height of the wetland canopies of these same classes. These data were then registered to one another to provide rigorous insight on the height of wetland on a class by class basis. Such data can then be used to derive other information on biomass and timber volume over an extended geographic area. Perhaps most importantly for the SRP, it provides a mechanism for not only monitoring the change in vegetation cover in heterogenous wetlands such as Steel Creek Delta, but changes either as increased height or density or reduced height or density of the individual classes can be evaluated through time if the same type of MSS and LIDAR data are obtained on an appropriate cycle.

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**Table 1. Wetland Classification Scheme for the Steel Creek Delta Using
April 26, 1985 Aircraft MSS Imagery**

<u>Class</u>	<u>Common Name</u>	<u>Scientific Name</u>
OW - Open Water		
EM - Emergent Marsh	Knot weed	<u>Scirpus cypernius</u>
	Cutgrass	<u>Leersia spp.</u>
	False nettle	<u>Boehmeria cylindrica</u>
	Water primrose	<u>Ludwigia spp.</u>
	Hydrolea	<u>Hydrolea quadrivalvis</u>
SS - Scrub/Shrub	Willow	<u>Salix spp.</u>
	Bottonbush	<u>Cephalanthus occidentalis</u>
DSF - Deciduous Swamp Forest	Bald cypress	<u>Taxodium distichum</u>
	Tupelo-gum	<u>Nyssa aquatica</u>
DBF - Deciduous Bottomland Forest	Cak	<u>Quercus spp.</u>
	Sweetgum	<u>Liquidambar styraciflua</u>
	Red maple	<u>Acer rubrum</u>
	Hickory	<u>Carya spp.</u>

**Table 2. Spectral Resolution of the AADS-1268 Daedalus
Multispectral Scanning System (MSS)**

<u>Channel</u>	<u>AADS - 1268</u>
1	0.42 - 0.45 μm
2	0.45 - 0.52
3	0.52 - 0.60
4	0.60 - 0.62
5	0.63 - 0.69
6	0.69 - 0.75
7	0.76 - 0.90
8	0.91 - 1.05
9	1.55 - 1.75
10	2.08 - 2.35
11	8.50 - 14.00

**Table 3. LIDAR Sensor System Characteristics for Data Collected
on the Steel Creek Delta on June 13, 1985**

<u>Flightline</u>	<u>Mode</u>	<u>Pulse Repetition Rate</u>	<u>Beam Divergence</u>	<u>Altitude</u>	<u>Spot Diameter</u>	<u>Aircraft Velocity</u>
5/2	Bathymetric	200 pps	5 mrad	150 m	1.6	100 m/sec
6/2	Fluorsensing	200 pps	5 mrad	250 m	3.2	100 m/sec

**Table 4. Steel Creek Delta Wetland Vegetation Acreage
April 26, 1985 using High Resolution Aircraft MSS Data**

<u>Class</u>	<u>Number of Pixels</u>	<u>Acres</u>	<u>Hectares</u>	<u>Percentage</u>
Water	1360	10.539	4.265	1.79
PE	3609	27.968	11.318	4.74
NPE	5207	40.352	16.329	6.84
SS	18120	140.421	56.824	23.81
DSF	25692	199.100	80.570	33.75
DBF	4296	33.392	13.472	5.64
Mask	<u>18756</u>	<u>146.916</u>	<u>58.819</u>	<u>24.44</u>
Total	77040	597.021	241.597	100.00

Table 5. Steel Creek Delta Wetland Vegetation Classification Accuracy Using April 26, 1985 High Resolution Aircraft MSS Data

	<u>PE</u>	<u>NPE</u>	<u>SS</u>		<u>DSF</u>		<u>DBF</u>	<u>Total</u>	<u>Percentage</u>
			<u>Willow</u>	<u>Buttonbush</u>	<u>Tupelo</u>	<u>Cypress</u>			
PE	2			1				2/3	66.7
NPE	1	4						4/5	80.0
SS			1	6				7/7	100.0
DSF					3	4	1	7/8	87.5
DBF	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u> </u>	<u>3</u>	<u>3/3</u>	<u>100.0</u>
Total	3	4	1	7	3	4	4	23/26	88.5

Table 6. Analysis of Variance Between Seven Wetland Classes and LIDAR Derived Height Information

<u>Source</u>	<u>Sums of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Squared Error</u>	<u>F-Value*</u>
Treatment (between)	7373	6	1228	58.46
Error (within)	<u>3804</u>	<u>181</u>	21	-
Total	11177	187	-	-

* Significant at the 0.0001 level.

Table 7. Analysis of Variance Between Seven Wetland Classes and LIDAR Derived Height Information

<u>Source</u>	<u>Sums of Squares</u>	<u>Degrees of Freedom</u>	<u>Mean Squared Error</u>	<u>F-Value*</u>
Treatment (between)	7376	4	1841	88.42
Error (within)	3811	183	20	-
Total	11177	187	-	-

* Significant at the 0.0001 level.



Fig. 1. A National High Altitude Photography Program (NHAP) Photograph of the Savannah River Swamp Adjacent to the Savannah River Plant. Thermal effluent from nuclear reactor cooling operations reaches the Savannah River swamp through Pen Branch and Steel Creek. Deltas have formed at the junction of the creeks and the swamp where the indigenous Cypress-Tupelo swamp forest has been lost. This study focuses on the identification of wetland biophysical information in the Steel Creek Delta region.

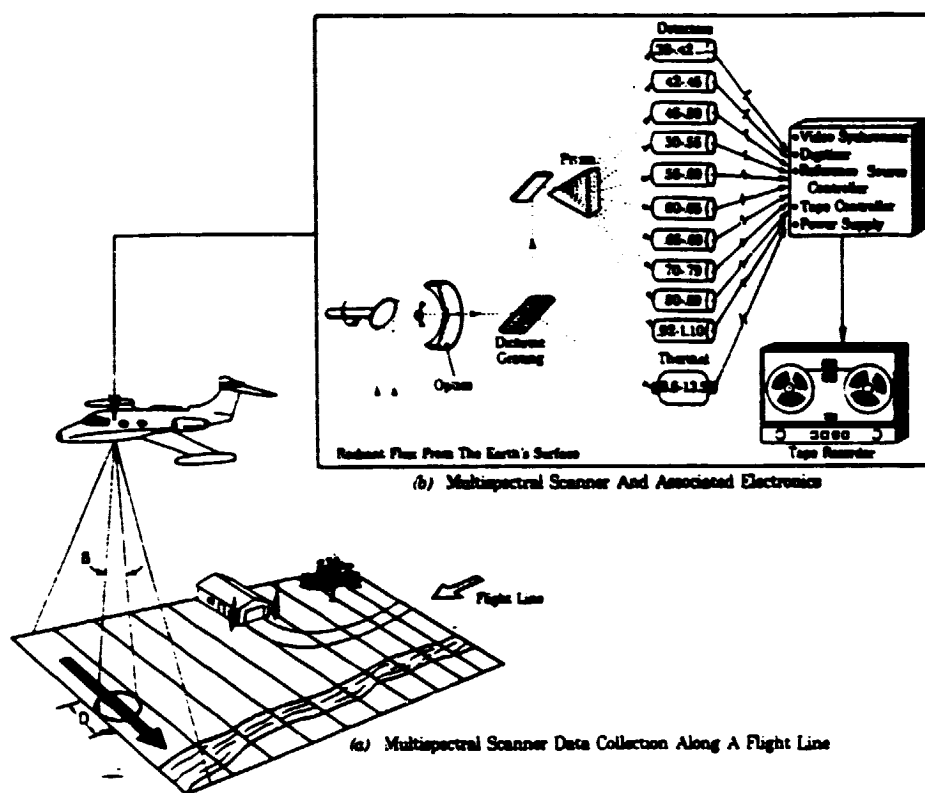


Fig. 2. An Aircraft Multispectral Scanner System (MSS)

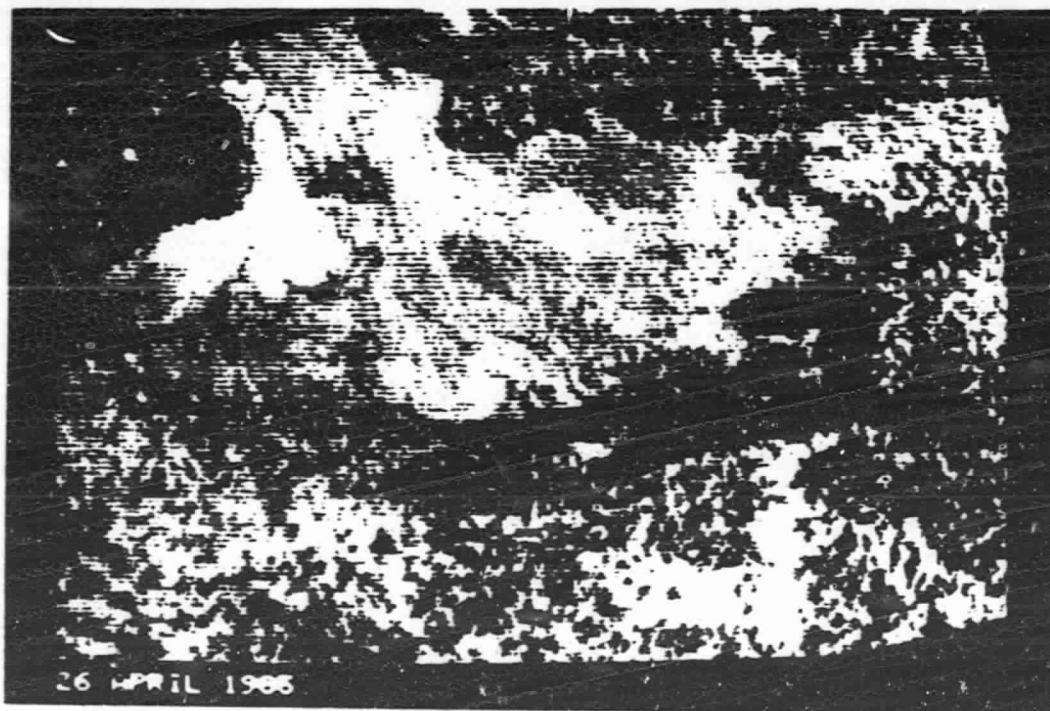


Fig. 3. A Color Infrared Color Composite of the April 26, 1985 Aircraft MSS Imagery After Radiometric Correction.

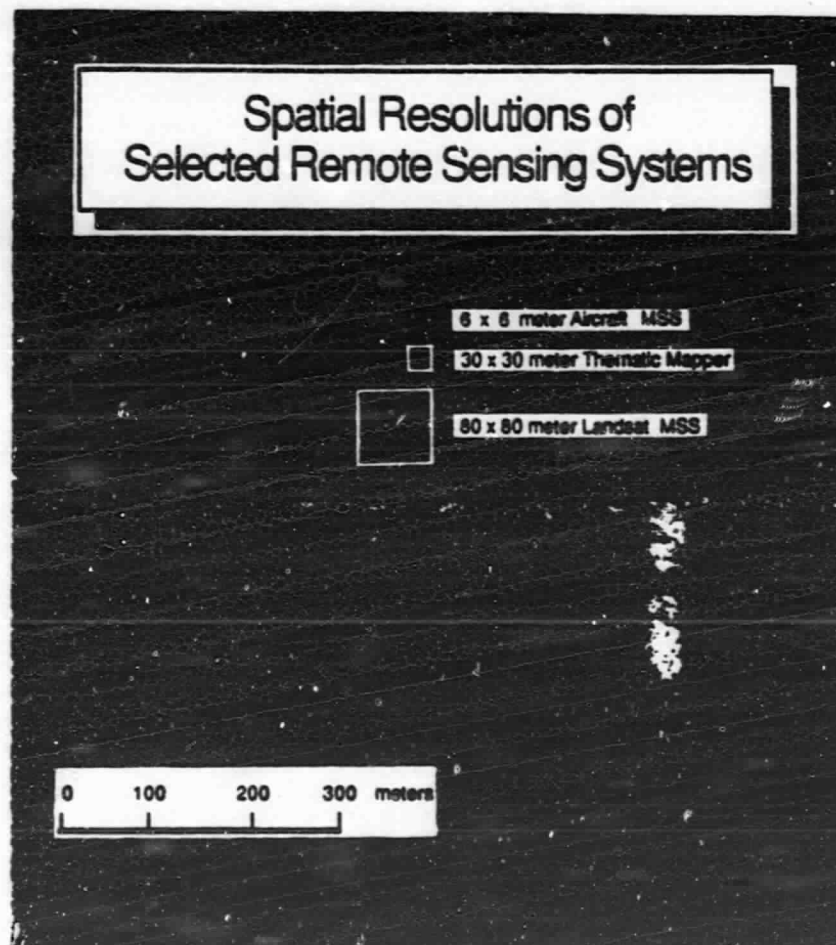


Fig. 4. A Natural Color Aerial Photograph of the Steel Creek Delta Overlaid with 6 x 6, 30 x 30, and 80 x 80 meter Spatial Resolution Cells.

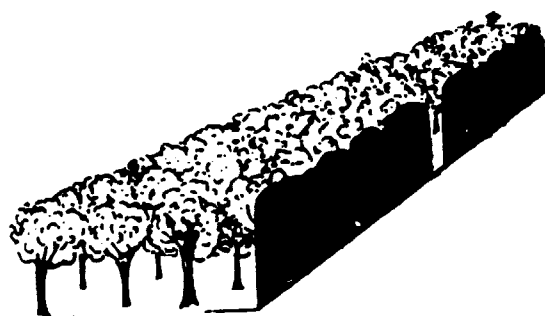
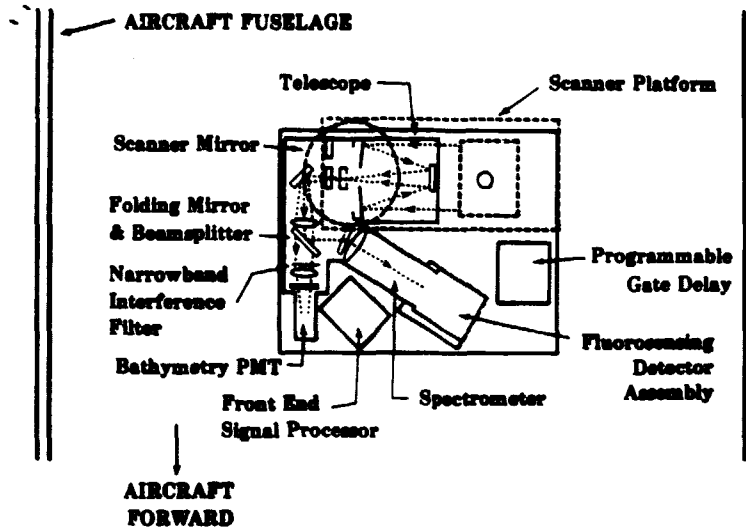


Fig. 5. A Hypothetical Profile Generated by a LIDAR System Operating Over Forested Terrain (Maclean and Krabill, 1986).

LIGHT DETECTING AND RANGING SENSOR SYSTEM (LIDAR)

Horizontal Cross Section View



Vertical Cross Section View

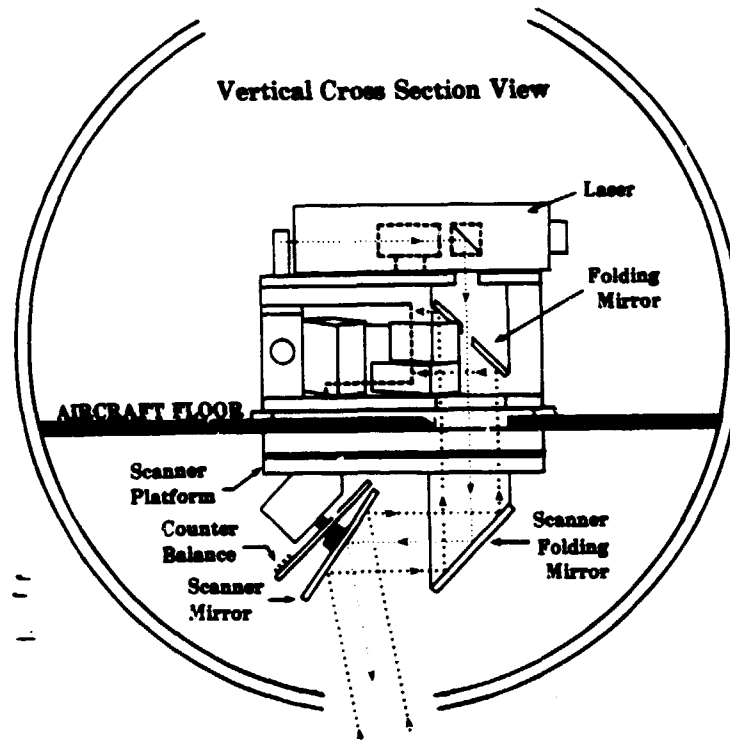


Fig. 6. The LIDAR Sensor System Shown Diagrammatically in Horizontal and Cross-Sectional Views (Krabill, 1986).

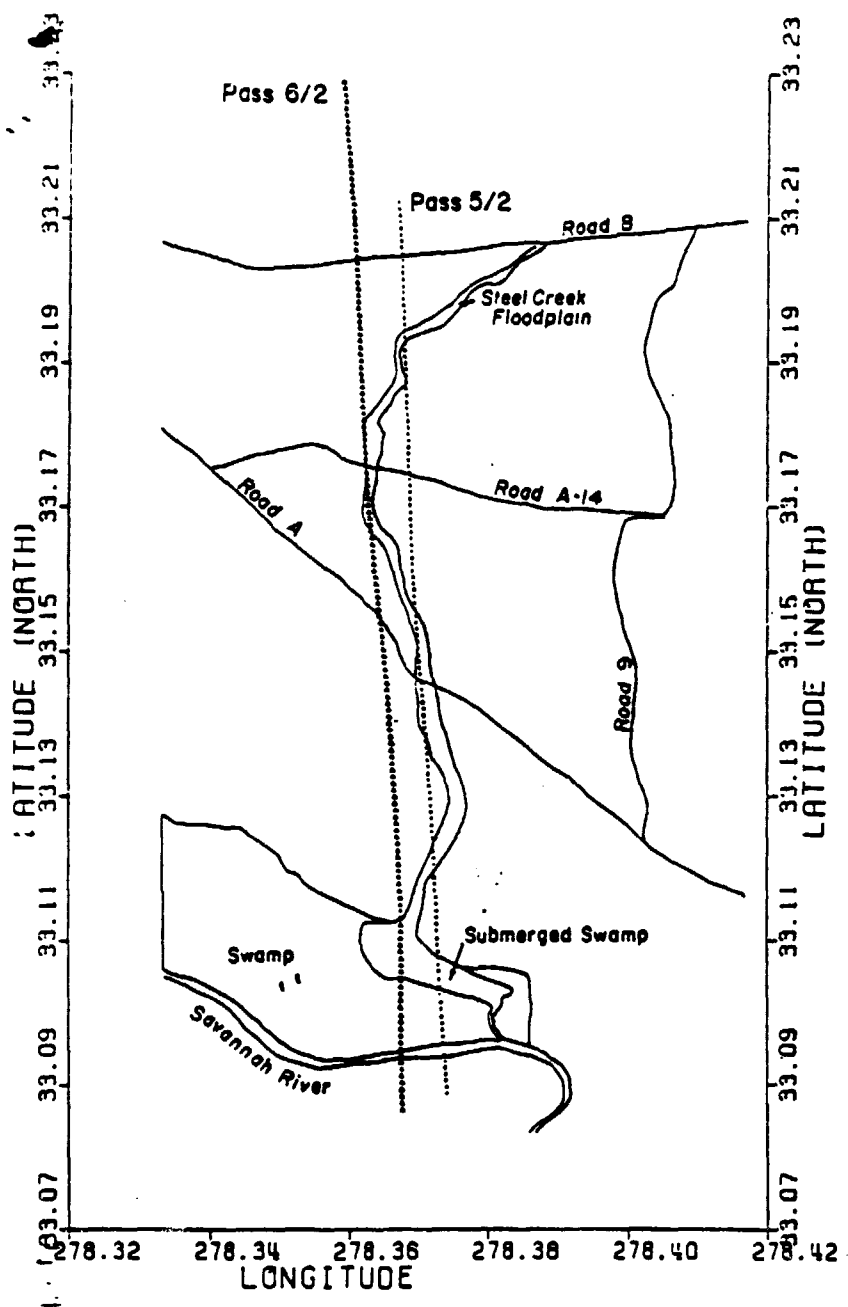


Fig. 7. Flightlines 5/2 and 6/2 Obtained Using the NASA LIDAR Sensor System on June 13, 1985.

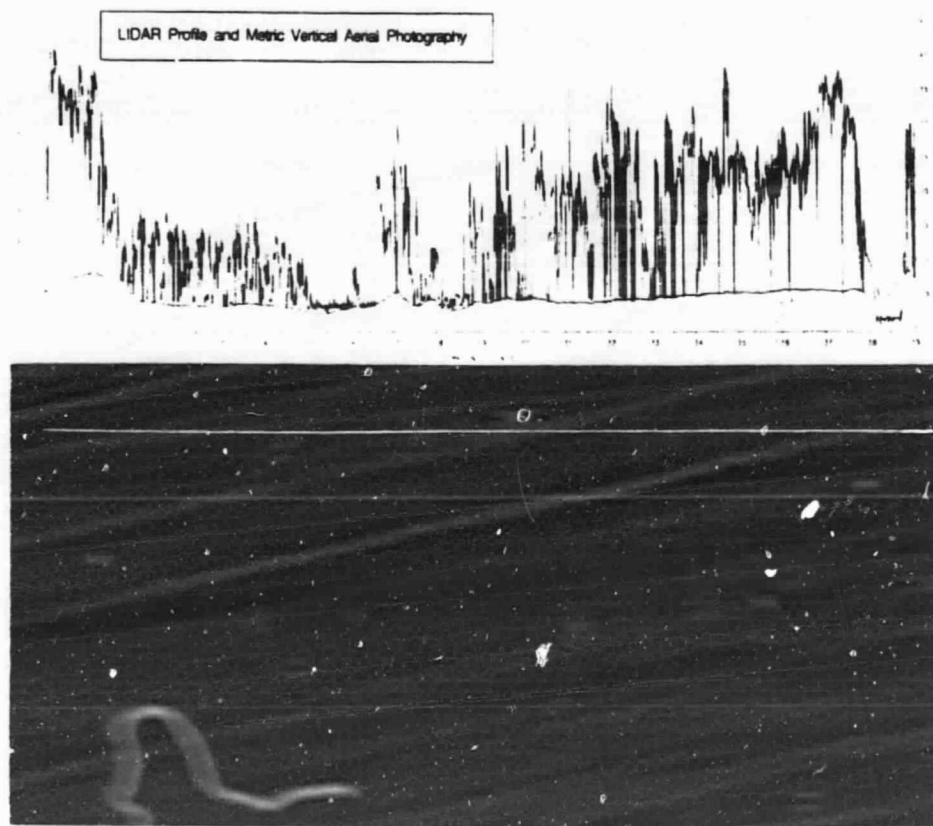


Fig. 8. Metric Aerial Photography of the Study Area Overlaid with the LIDAR Flightline 5/2 and the LIDAR Profile Height Information. The data were obtained by NASA personnel on June 13, 1985.

LIDAR Profile and 35mm Vertical Aerial Photography
Obtained on 13 June 1985



Fig. 9. LIDAR Profile and 35 mm Vertical Aerial Photography
Obtained on June 13, 1985. Scrub/Shrub at location b are easily
discernible on both the profile and the aerial photography.

Similar to
Fig 8

Fig. 10. A Portion of the LIDAR Height Information Registered with the Land Cover Class Information Derived from an Analysis of Aircraft MSS Data Obtained on June 13, 1985 on a Pixel by Pixel Basis.

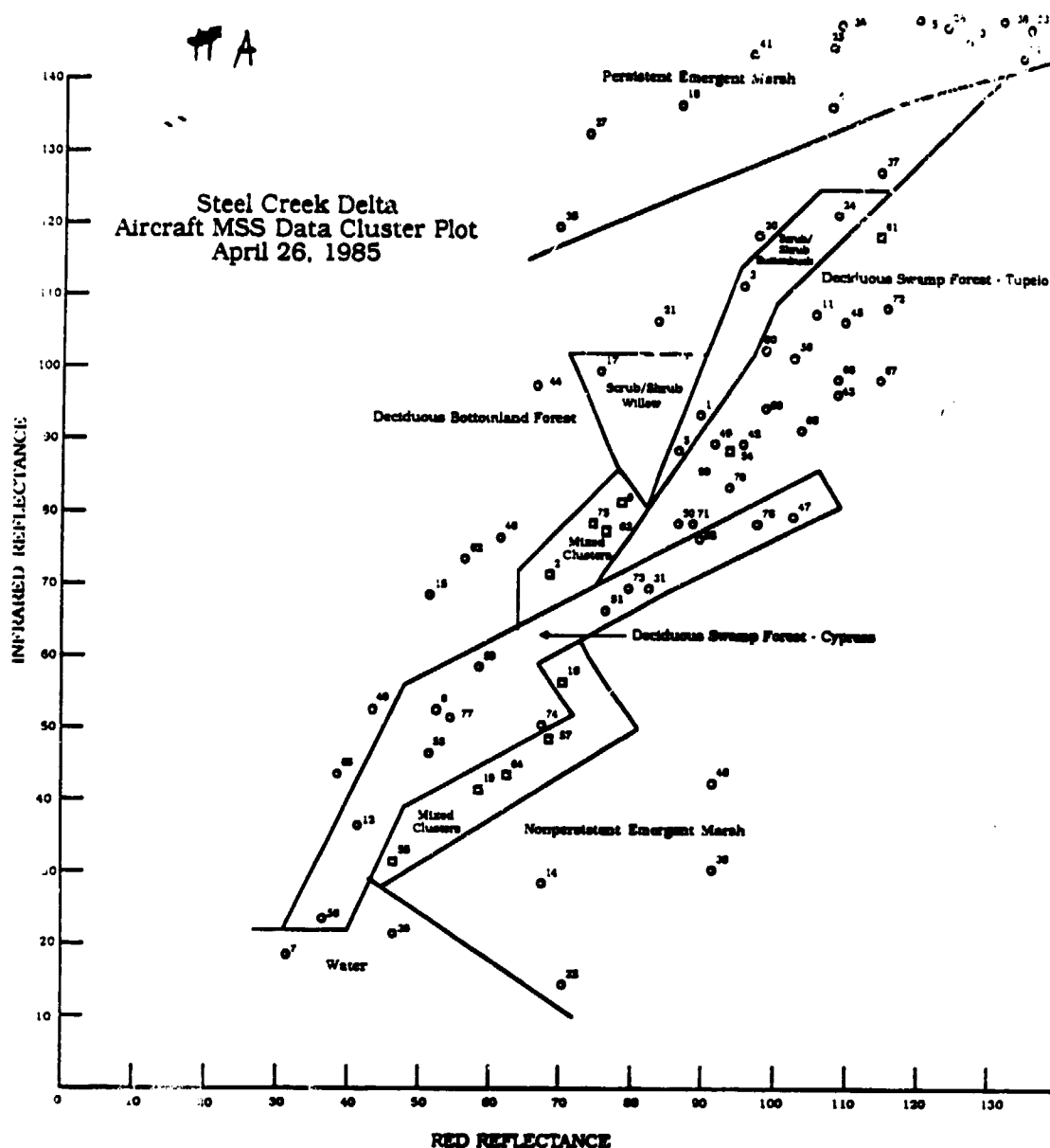


Fig. 11. Seventy-Seven (77) Clusters Extracted from the April 26, 1985 Aircraft MSS Imagery are Shown in 2-Dimensional Feature Space (red and near-infrared). The classes are described in Table 1. Ten of the clusters could not be accurately labeled. Therefore, an iterative clustering procedure was used to isolate and label the clusters.

11B

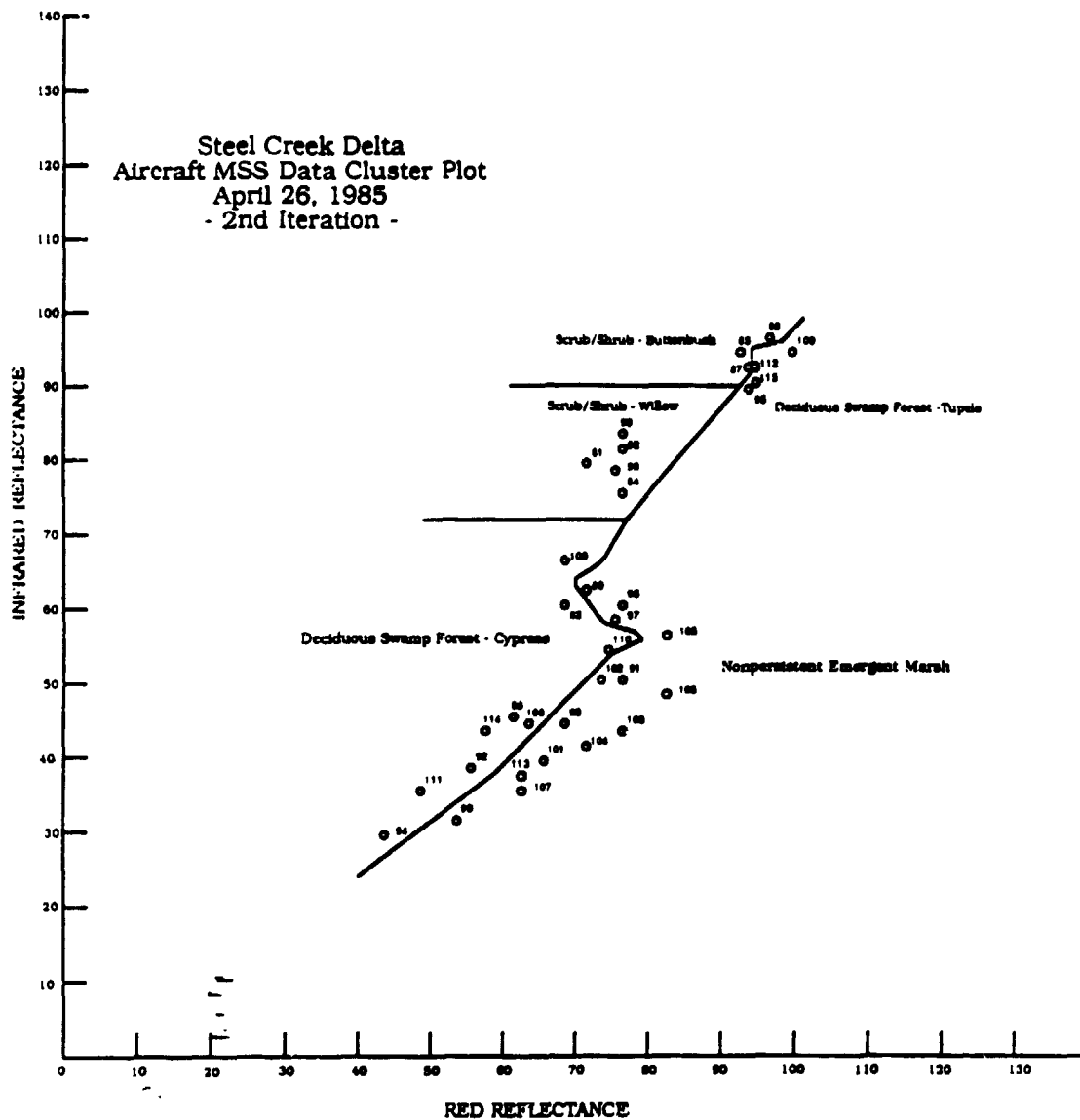


Fig 11B

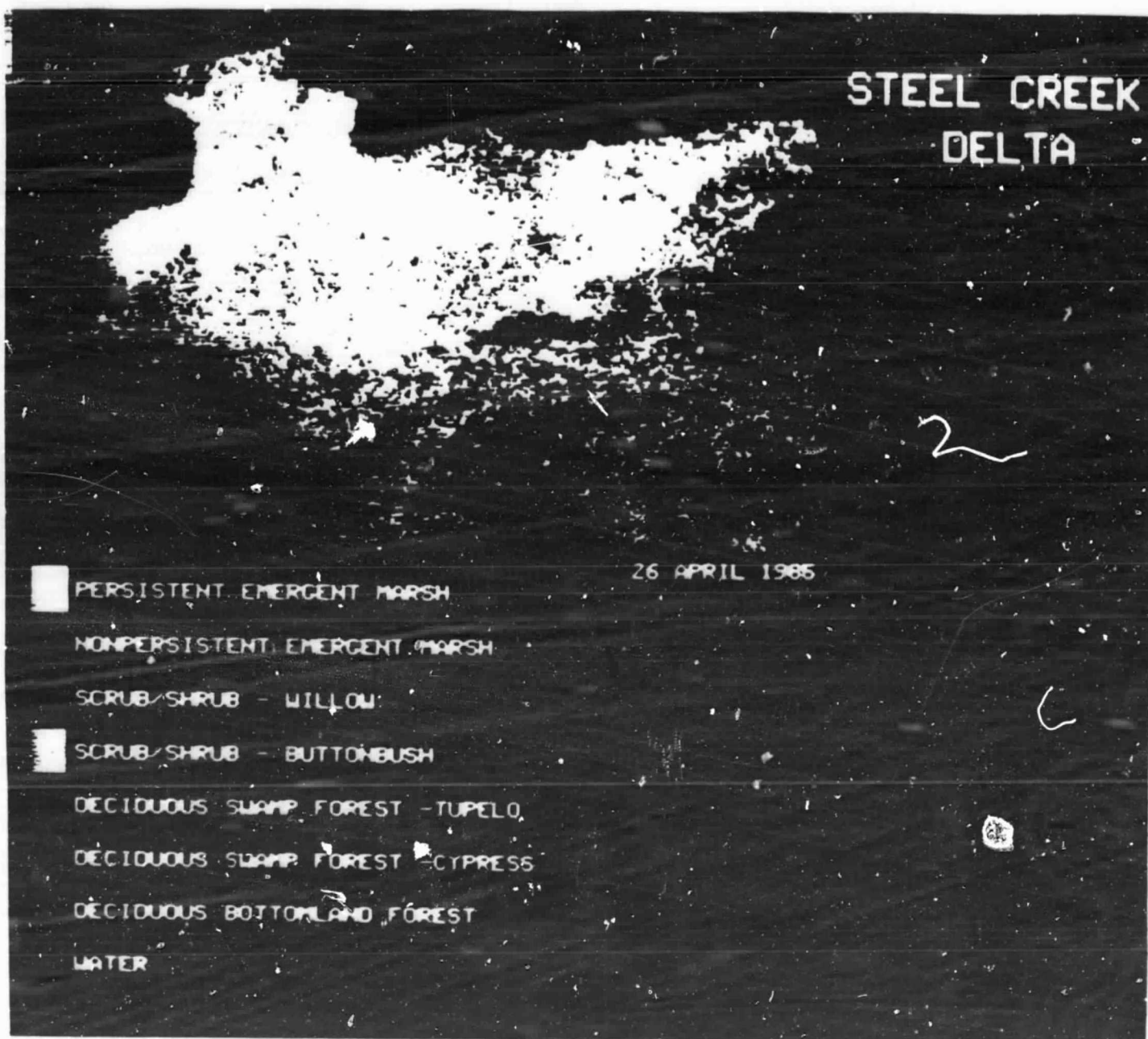


Fig. 12. Classification Map of the April 26, 1985 Data
 Depicting All Classes Discriminated. Note that both willow and
 buttonbush of the Scrub/Shrub (SS) class are present. Also,
 Tupelo and Cypress categories of the Deciduous Swamp Forest
 (DSF) class are included.

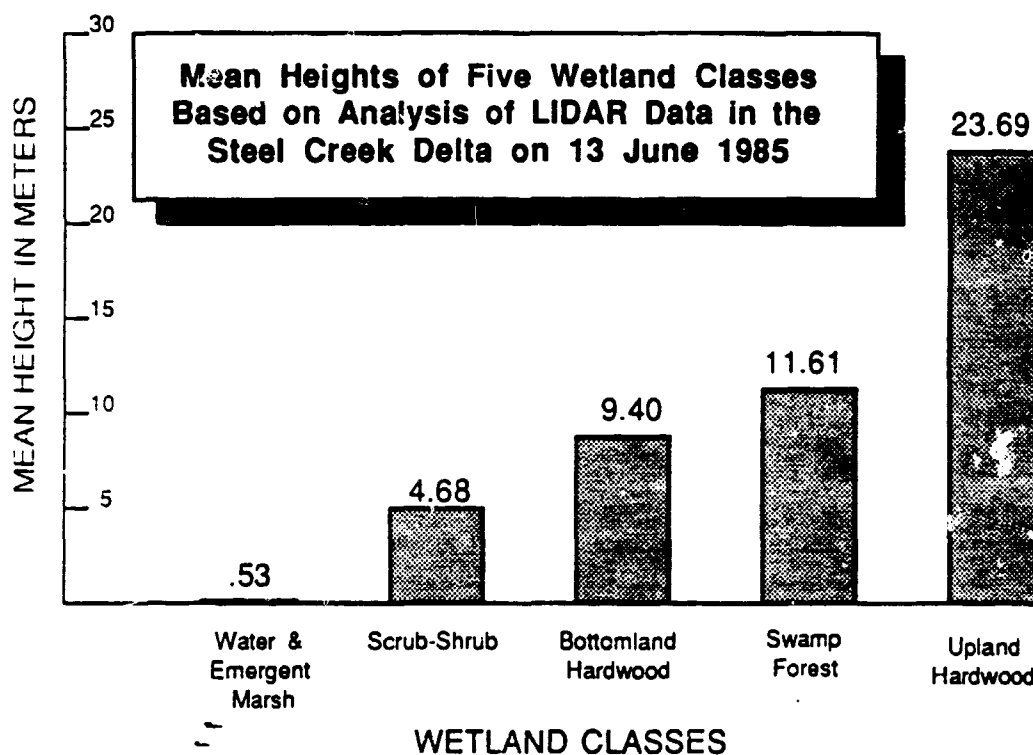


Fig. 13. Mean Heights of Five Wetland Classes Based on Analysis of LIDAR Data in the Steel Creek Delta on June 13, 1985.

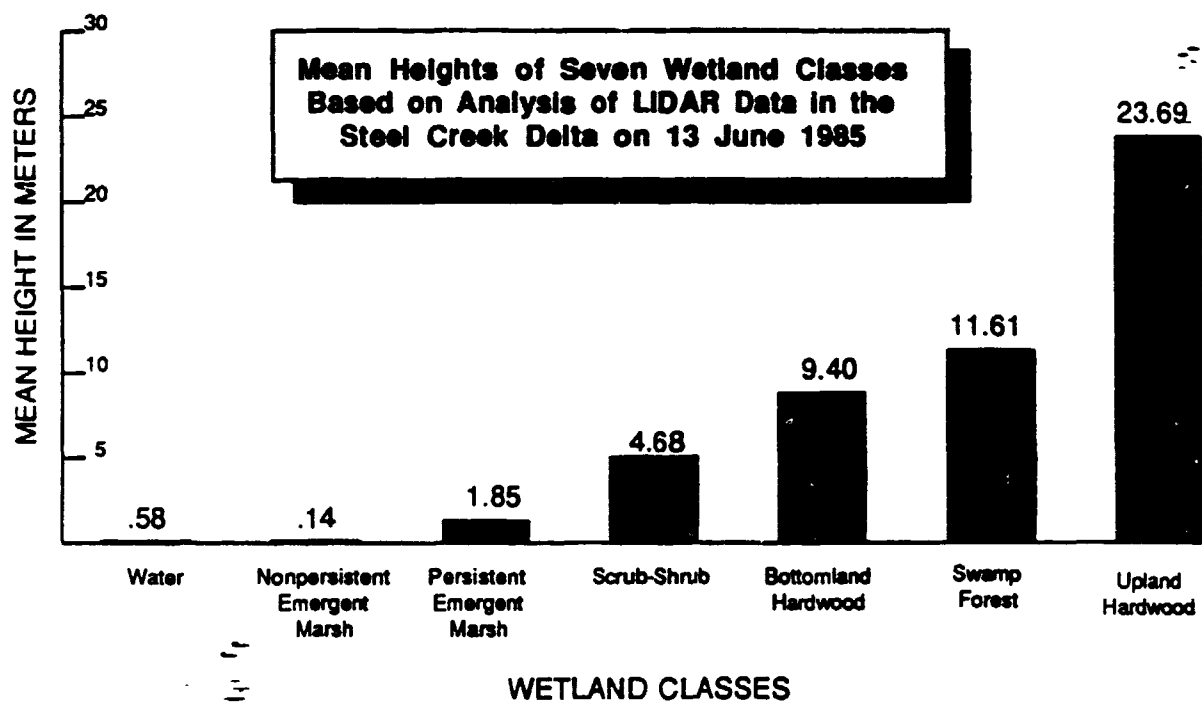


Fig. 14. Mean Heights of Seven Wetland Classes Based on Analysis of LIDAR Data in the Steel Creek Delta on June 13, 1985.

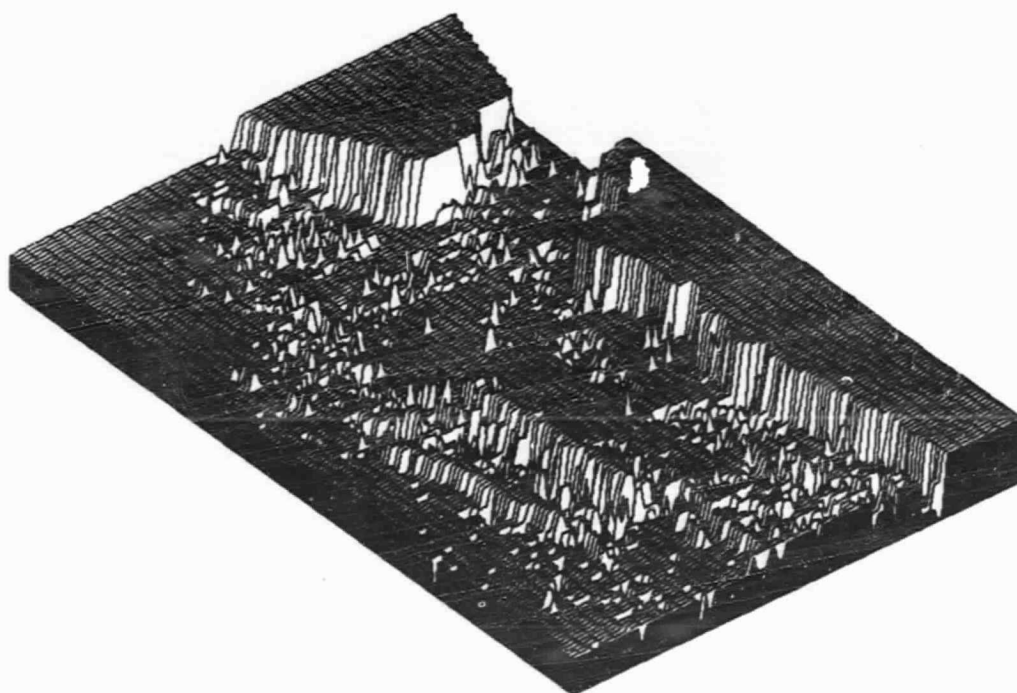


Fig. 15. Three-Dimensional Display of the 26 April 1985 MSS Landcover Classification Based on Height Information Derived from the June 13, 1985 LIDAR Overpass.

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